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Evaluating NOAA-20 and S-NPP VIIRS Radiometric Consistency

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ABSTRACT

The Visible Infrared Imaging Radiometer Suite (VIIRS) onboard S-NPP provides global coverage once per day for the reflective solar bands. With the successful launch of NOAA-20, the global coverage of VIIRS has now been doubled. In order to use NOAA-20 VIIRS data for environmental related studies, the radiometric performance of VIIRS needs to be independently validated. In addition, for long term studies that use data from multiple satellites instruments, it is imperative to have radiometrically accurate and consistent data products from all the instruments. This study uses SNO (Simultaneous Nadir Overpass) and extended SNO over Saharan desert to assess the radiometric performance of NOAA-20 VIIRS relative to S-NPP VIIRS. Since direct SNO doesn't exist between NOAA-20 and S-NPP, the study uses MODIS as a transfer radiometer. Both NOAA-20 and S-NPP have SNOs with MODIS. Double differencing technique is used to estimate the radiometric bias between the two VIIRS instruments. The study suggests that NOAA-20 VIIRS reflective solar bands are consistently lower in reflectance than that from S-NPP VIIRS by about 2%. Larger bias is observed for bands M5 (0.67 µm) and M7 (0.86 µm) bands mainly because S-NPP VIIRS absolute calibration for these bands is biased high by about 2%. The impact on bias due to spectral differences between the two VIIRS instruments is quantified using hyperspectral measurements from Sciamachy.

Keywords: NOAA-20 VIIRS calibration, VIIRS RSB bias, VIIRS and MODIS comparison, NOAA-20 radiometric accuracy, SNPP and NOAA-20 comparison

1. INTRODUCTION

NOAA-20 VIIRS has been performing very well since launch. VIIRS has 13 reflective solar bands (RSBs), 1 day/night band (DNB) and 8 thermal emissive bands (TEBs). The operational radiometric calibration for RSB is based on solar diffuser and solar diffuser stability monitor. Details about VIIRS instrument design and onboard calibration system can be found in previous studies [1]. The solar diffuser BRDF is characterized on-orbit early after launch using yaw maneuver. In an effort to improve the calibration quality, VIIRS onboard NOAA-20 has gone through a number of major look up table updates since launch. Thus, continuous validation of the instrument performance is critical in order to ensure that the radiometric accuracy and stability of the instrument is well within the specification. There are a number of independent satellite instrument validation techniques such as intercomparison using SNO, comparing over well characterized Earth calibration sites, lunar trending, DCC [2-6]. S-NPP VIIRS performance is very stable and is regularly monitored by intercomparing with other instruments such as AQUA MODIS using SNO, SNOx, stable vicarious calibration sites, DCC, and moon [2, 3, 6]. Since S-NPP VIIRS is stable and has been rigorously calibrated and validated, N20 VIIRS radiometric performance can be assessed by intercomparing with SNPP. To use VIIRS data in long term scientific applications and to establish a long term data continuity of environmental data records, VIIRS calibration should be consistent and independent of satellite platform. This study quantifies how well NOAA-20 VIIRS SDR agree with S-NPP VIIRS.

This study uses SNO technique for intercomparison. Since N20 and SNPP don't have direct SNOs between them, a double differencing approach is used for intercomparison. Both N20 and SNPP have SNOs with AQUA MODIS. Past studies describe how double differencing can be used in sensor comparison [7, 8]. The assumption is that the calibration bias if present in any of the MODIS bands gets cancelled out after double differencing and the result indicates the bias between two VIIRS instruments. Spectral differences between the two VIIRS instruments is analyzed using spectral band adjustment factors (SBAF). SBAF is calculated using Sciamachy to account for small spectral difference between SNPP and N20. Time series of absolute radiometric bias is analyzed to quantify the radiometric performance of N20 VIIRS since launch. Bias between the VIIRS onboard N20 and SNPP is expected

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to be as small as possible. However, it is not uncommon to observe bias on the order of 1-2% for some bands mainly due to a number of uncertainties contributed by calibration uncertainties, BRDF, cloud contamination, spectral differences and atmospheric absorption variabilities.

2. METHODOLOGY

2.1 SNO Data Sets

Polar SNOs over snow flats and extended SNOs over Saharan deserts in tropical region are used in the study to evaluate the radiometric consistency between NOAA-20 VIIRS and S-NPP. VIIRS on-orbit bias is characterized to quantify the instrument performance. Most of the reflective solar bands are analyzed. MODIS bands that matches with VIIRS M2 (0.412 um) and M3 (0.445 um) bands are mostly saturated over polar snow at lower solar zenith and are thus compared only at high solar zenith angles. VIIRS bands M9-11 are not reliable to compare over snow mainly due to small signal strength and larger uncertainty associated with spectral bias resulting from highly non-uniform target spectra as seen in figure 1. For each SNO event, VIIRS operational reflectance data corresponding to SNPP and N20 are collected. For AQUA MODIS, collection 6 reflectance data are used. VIIRS and MODIS matching bands are shown in Table 1.

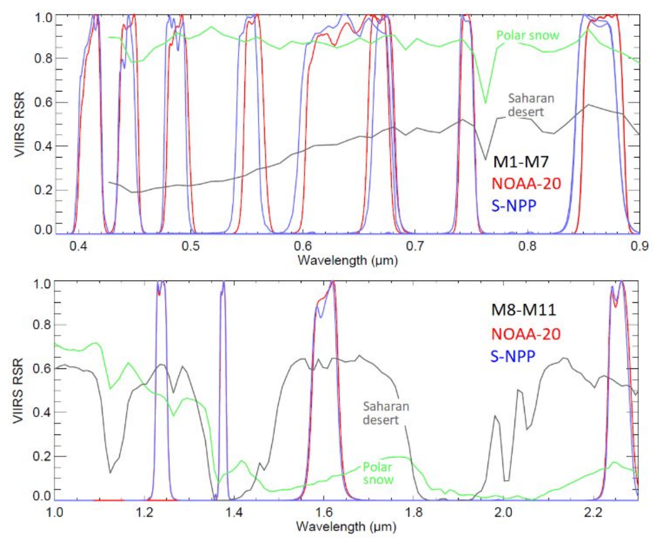

Figure 1. VIIRS RSRs and spectral features over polar snow and Saharan desert

Table 1. VIIRS and MODIS matching bands (spectra and table)

VIIRS		MODIS	
Band	Wavelength (µm)	Band	Wavelength (µm)
M1	0.402 - 0.422	8	0.405 - 0.420
M2	0.436 - 0.454	9	0.438 - 0.448
M3	0.478 - 0.498	10	0.483 - 0.493
M4	0.545 - 0.565	4	0.545 - 0.565
M5 I1	0.662 - 0.682 0.600 - 0.680	1	0.620 - 0.670
M7 I2	0.846 - 0.885 0.850 – 0.880	2	0.841 - 0.876
M8	1.230 - 1.250	5	1.230 - 1.250
M10	1.580 - 1.640	6	1.628 - 1.652
M11	2.225 - 2.275	7	2.105 - 2.155

2.2 Satellite Intercomparison

All SNO events since 01/01/2018 are analyzed (Figure 2). For each SNO, VIIRS (www.class.noaa.gov) and MODIS (https://lpdaac.usgs.gov/data_access/data_pool) reflectance data are collected and compared. A MODIS ROI of size 400*400 is selected with center at SNO intersection. Matching VIIRS image is mapped into MODIS lat/lon grid. For senzen<5°, VIIRS and MODIS observations are compared to calculate S-NPP VIIRS bias relative to MODIS. Similarly, the process is repeated for NOAA-20 VIIRS to compute its bias relative to MODIS. Since comparison at large solar zenith adds uncertainties from BRDF, atmospheric variabilities and RSR differences, this study uses solar zenith angle limited to less than 75° for all M bands except for M2. Since matching MODIS bands of VIIRS M2 gets saturated at smaller solar zenith angles, M2 used in this study over polar SNO have solar zenith larger than 70°. VIIRS M3 is not used in this study as the equivalent MODIS band (Band 10) gets mostly saturated and the results are not reliable. Similarly, VIIRS band M6, M9-11 are also not used over polar SNO and M6, M11 are not used over desert SNOx. M6 is mostly saturated over snow and desert.

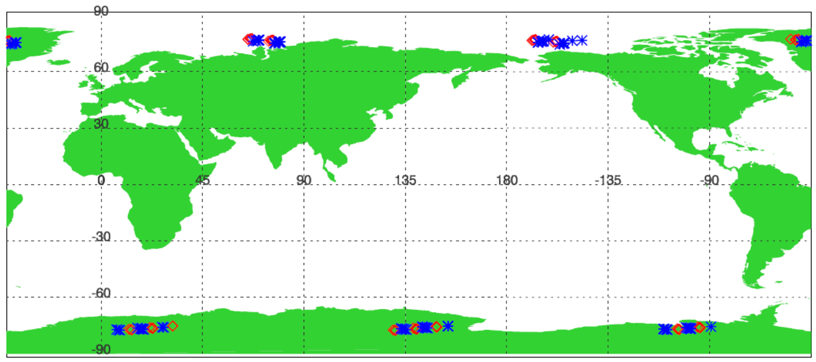

Figure 2. SNO events over polar region since 01/01/2018, Red: NOAA-20 and AQUA; Blue: S-NPP and AQUA

After getting bias trend of each VIIRS instrument relative to AQUA MODIS, double differencing is used to estimate S-NPP and NOAA-20 VIIRS radiometric consistency. The difference in bias of two VIIRS instruments relative to MODIS indicates the bias between the two VIIRS instruments. To compute the absolute bias, the impact due to RSR differences between the two VIIRS instrument needs to be accounted for. Spectral band adjustment factors (SBAF) is computed for each matching VIIRS bands based on analysis using hyperspectral measurements from Sciamachy (https://www-pm.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SBAF). NOAA-20 VIIRS is scaled with SBAF to remove the bias associated with spectral differences with S-NPP. Temporal trends of absolute bias between the two VIIRS instruments since early launch are analyzed.

2.3 Instrument comparison using reflectance vs. Radiance

Users need to be aware about the solar irradiance models used to generate SDR products because difference in solar models can easily lead to more than 3% bias between two VIIRS instruments. This study uses reflectance product from VIIRS and MODIS. VIIRS and MODIS reflectance data are free of solar models and thus their intercalibration is not affected by difference in solar model. However, if radiance products are compared, the differences in solar models can cause more than 3% bias for some bands which needs to be accounted properly to quantify the absolute radiometric consistency. This is because S-NPP VIIRS uses Kurucz spectrum [5] for calibration, unlike the Thuillier model [9] used in NOAA-20 VIIRS calibration. Figure 3 shows how the two VIIRS instruments compared in radiance can be impacted by solar model difference. Figure suggests that M2 and M7 have largest impact with more than 2.5% difference in radiance caused by differences in solar models. This study uses reflectance data to evaluate the radiometric consistency between VIIRS and thus the observed bias is independent of solar models used.

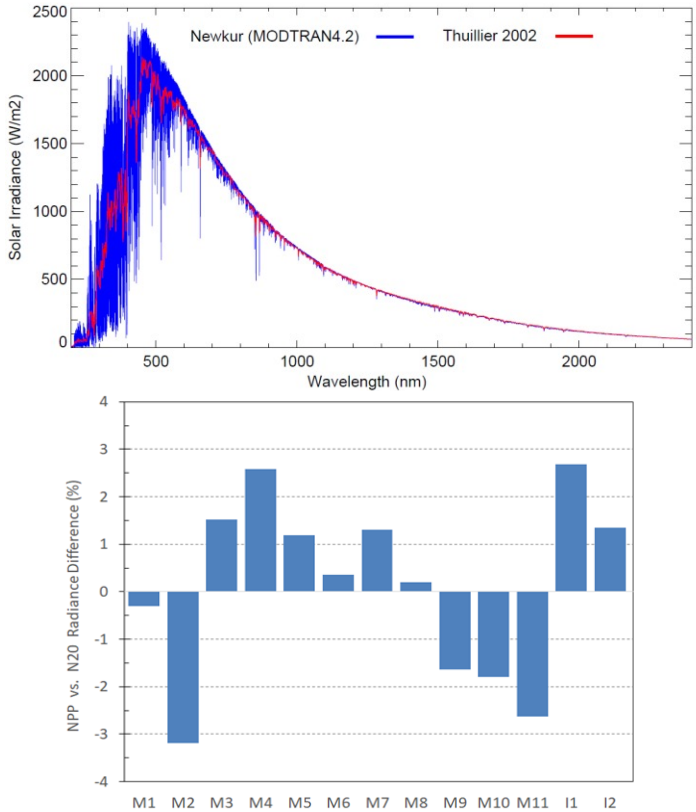

Figure 3. Top: Solar models used in NOAA-20 VIIRS (Thuillier) and S-NPP VIIRS (Kurucz based on MODTRAN 4.0), Bottom: Differences in radiance calculated by two VIIRS instruments with different solar models. Band M2 suggest lager than 3% difference in radiance.

2.4 Spectral bias for VIIRS

As explained earlier, there exists some minor differences in RSRs between the two VIIRS instruments. During intercomparison, bias resulting from RSR differences needs to be accounted for. Spectral Band Adjustment factors (SBAF) is computed for each VIIRS band using Sciamachy (https://www-pm.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SBAF). SBAF is used to scale NOAA-20 VIIRS bias to match with S-NPP equivalent RSRs. Table 2 shows the spectral bias values estimated for NOAA-20 VIIRS M bands using polar snow spectra. Table suggests that spectral bias is largest for M4 over desert (3.2%). For the rest of the M bands over both the desert and snow, spectral bias is on the order of 1% or less.

Table 2. Spectral bias for NOAA-20 VIIRS bands relative to equivalent S-NPP VIIRS

Target	M1	M2	M3	M4	M5	M7	M8	M10	I1	I2
South Pole	0.3%	0.1%	-	-0.8%	0.2%	-0.4%	-	-	0.3%	-0.4%
Libyan Desert	-1.2%	0%	0.1%	3.2%	0.3%	1%	0.1%	0.2%	-	-

3. RESULTS AND DISCUSSION

Radiometric consistency between S-NPP and NOAA-20 is assessed by estimating the relative radiometric bias. VIIRS instruments onboard S-NPP and NOAA-20 suggest bias for all the reflective solar bands (RSB). NOAA-20 VIIRS observed reflectance is consistently lower than that for S-NPP. Details are explained in section 3.1.

3.1 VIIRS Radiometric Bias

Figure 4a shows the radiometric bias time series of S-NPP VIIRS (Blue) relative to MODIS and NOAA-20 VIIRS (Red) relative to MODIS computed using SNO. All the bands suggests that NOAA-20 VIIRS is biased lower than S-NPP. There is a big jump in bias near March (after DSL 120) especially for bands M1-M4. This big change is caused by the LUT update which started to account for solar diffuser (SD) degradation. Before March 23, 2018, VIIRS was calibrated assuming no solar diffuser degradation. Early operational calibration didn't account for SD degradation mainly due to lack of enough SDSM data for degradation characterization. Yaw maneuver to characterize SD BRDF was performed in late January, 2018 [10].

Except bands M5 and M7, the rest of the M bands indicate bias ranging from 2-3%. M5 and M7 suggest large biases on the order of 4% or more mainly because S-NPP VIIRS absolute calibration is overestimated by about 2% [2, 3]. Similar to M bands, I bands also suggest consistently lower responsivity for NOAA-20 compared to S-NPP. The temporal trends for bias are nearly stable after DSL 200. More recently, NOAA-20 I1 indicates about -2% bias whereas I2 indicate about -4% bias relative to S-NPP (Fig. 4b). M7 and I2 RSRs match very well and thus suggests similar bias on the order of -4%. After accounting for -2% bias in NOAA-20 VIIRS for all M bands and +2% calibration overestimation in S-NPP VIIRS M5, M7, and I2, the two VIIRS instruments agree very well to within 1%.

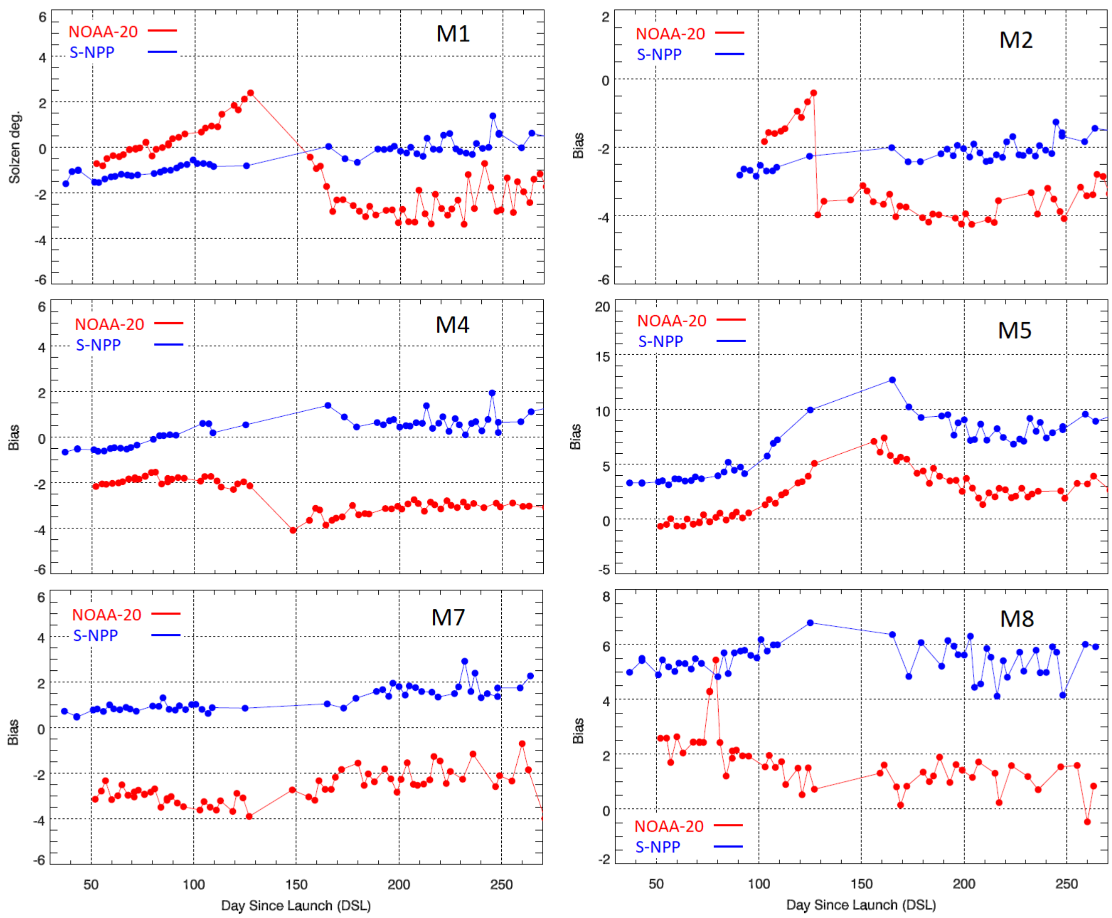

Figure 4a VIIRS bias time series relative to MODIS. The difference in two VIIRS bias time series (double difference) provides relative radiometric consistency between VIIRS onboard NOAA-20 and S-NPP.

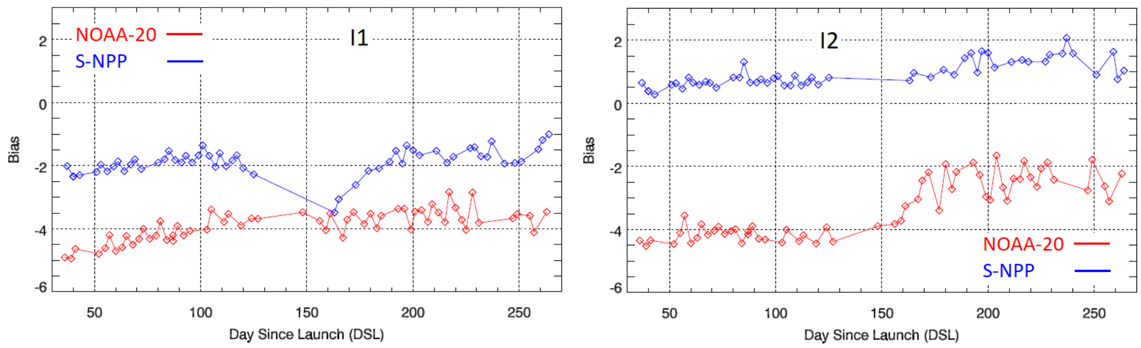

Figure 4b. VIIRS bias time series for I bands

Bias estimated using extended SNO over tropical desert suggests that NOAA-20 VIIRS observed reflectance is consistently lower than that for S-NPP. Bias magnitudes agree with polar SNO results very well to within 1%, except M4 that shows 1.5% difference. M4 bias over desert is ~2% compared to 3.5% over polar snow. As indicated in section 2.5, M4 has large spectral bias over desert of about 3.2%. It is possible that the difference in bias magnitudes over two sites can be attributed to uncertainties associated with RSR differences. Table 3 shows the absolute bias values for NOAA-20 VIIRS relative to S-NPP estimated using two techniques, SNO over polar snow and extended SNO over Saharan deserts. Near consistent bias for NOAA-20 VIIRS RSB could be possibly attributed to prelaunch calibration uncertainties and needs further investigation.

Table 3. NOAA-20 VIIRS bias relative to S-NPP VIIRS.

Method	NOAA-20 Bias Relative to S-NPP (%)									
	M1	M2	M3	M4	M5	M7	M8	M10	I1	I2
SNO	-2.7%	-2.0%	-	-3.5%	-5.2%	-3.5%	-4.0%	-	-1.9%	-3.7%
SNOx	-2.5%	-2.5%	-2.5%	-2.0%	-5.0%	-4.0%	-3.0%	-2.0%	-	-

Uncertainties in bias estimation mainly comes from individual instrument calibration uncertainties, BRDF, residual subpixel cloud contamination, uncertainty in SBAF due to lack of in-situ hyperspectral measurements over the sites, and bias analysis over shorter time interval. Users need to be aware that this study is performed over high reflectance sites (snow and desert) with VIIRS dual gain bands utilizing low gain over the sites. Thus, estimated bias is based on analysis of data with low gain. However, based on the lesson learnt from S-NPP VIIRS [2], it is expected that both low gain and high gain should exhibit similar bias.

CONCLUSION

Radiometric consistency between NOAA-20 and S-NPP VIIRS reflective solar bands are independently validated using two techniques, intercomparison using SNO over polar snow and using extended SNO over Saharan desert. Intercomaprison is performed using reflectance and bias is estimated after accounting for RSR differences between the two VIIRS instruments. Both methods suggest that NOAA-20 VIIRS observed reflectance is consistently lower than that for S-NPP for all reflective solar bands under study by 2-3%. Larger bias exists for M5 (5%) and M7 (4%) because S-NPP VIIRS M5 and M7 calibration are biased high by nearly 2%. Bias results over polar snow and tropical deserts agree to within 1% for most bands. The presence of bias for NOAA-20 is likely attributed to prelaunch calibration uncertainties. The NOAA-20 VIIRS bias needs to be regularly monitored and further investigated for root cause.

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